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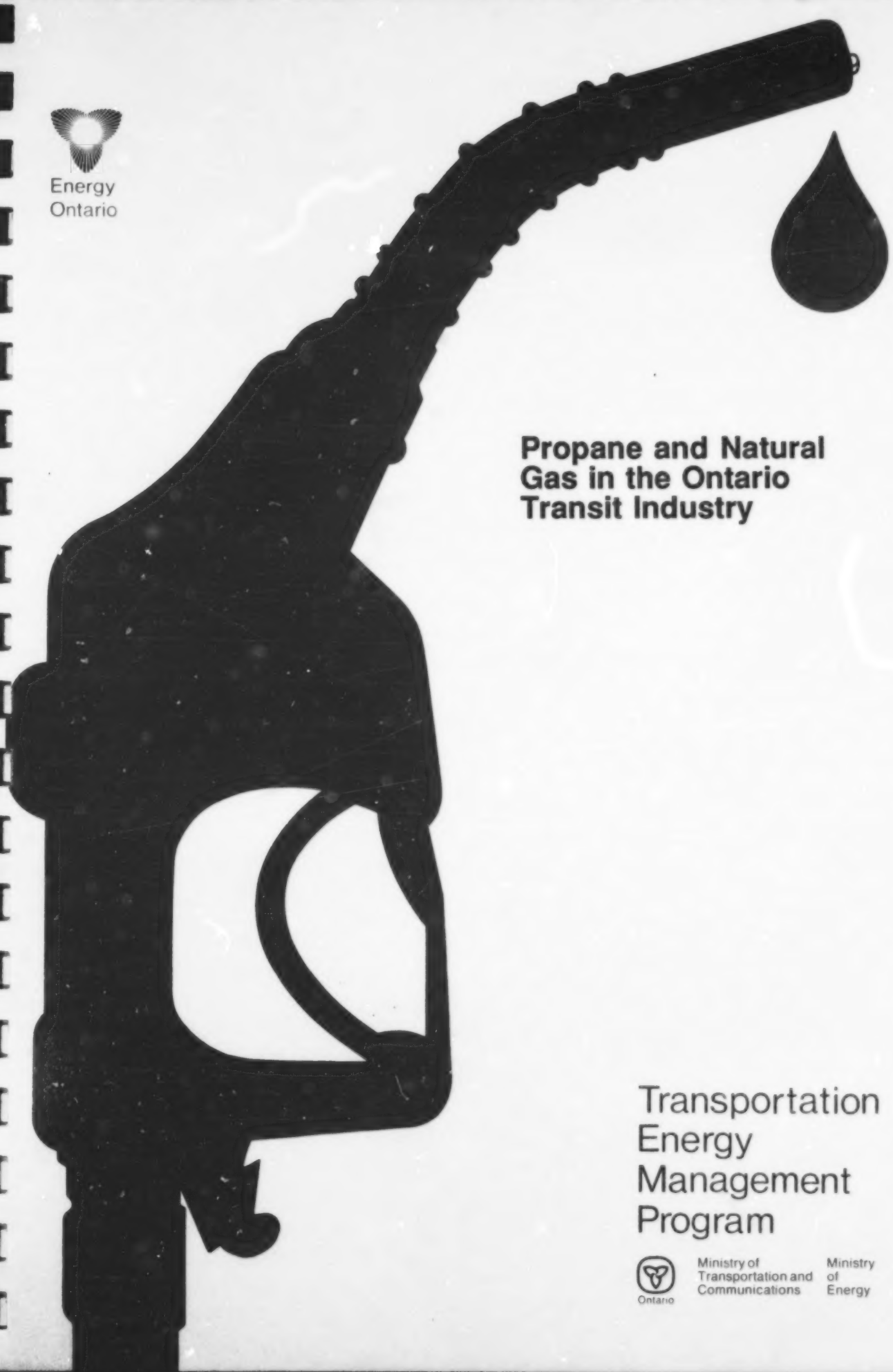

Propane and Natural Gas in the Ontario Transit Industry

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T. Topaloglu
Head, Automotive Energy Section
Automotive Technology and Systems Office

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PROPANE AND NATURAL GAS IN THE ONTARIO TRANSIT INDUSTRY

Toros Topaloglu

ABSTRACT

In two independent and unique demonstrations, Ottawa-Carleton Transpo and Hamilton Street Railway are assessing the viabilities of propane and natural gas as alternatives to diesel fuel in transit bus fleets. The potential advantages of these alternatives are greater availability, consistent quality, lower cost, lower exhaust emissions and lower noise levels.

The demonstrations were planned to include a test phase to assess technical viability followed by an extensive revenue service evaluation and rider/driver surveys. To date, the test phase has been completed and the two transit authorities are proceeding with the in-service evaluation.

The demonstrations have already produced substantial experience and know-how with the use of propane and natural gas in transit environments. In this paper, the experienced gained in the engine and bus conversions, the performance and reliability of the buses and fuelling facilities, the preliminary economics of the alternative fuels and the results of the test phase are presented.

INTRODUCTION

The Ministry of Transportation and Communications (MTC) has initiated joint demonstration programs with Ottawa-Carleton Transpo (OC Transpo) and Hamilton Street Railway (HSR) to assess the feasibility and economics of using propane and natural gas as transit bus fuels. These demonstrations are jointly funded by the Ontario Ministry of Energy (MENY) and Energy Mines and Resources Canada (EMR) and are supported by Union Gas and Superior Propane. In this paper, the status of these demonstrations and the results of a parallel engine dynamometer evaluation are presented.

The OC and HSR demonstrations are based on the premise that propane and natural gas may prove to be viable alternatives to diesel fuel and, in fact, may be even superior in some aspects. The potential advantages of the gaseous fuels include:

- lower cost per unit of energy
- almost no particulate emissions
- less noise, vibration and smell
- security of fuel supply

However, these advantages will be attained only when the following tasks are successfully completed:

- purchase, operate and maintain suitable fuel storage and dispensing systems;
- purchase, operate and maintain suitable gaseous fuel engines;
- install suitable on-board fuel tanks;
- modify bus storage facilities and practices.

The objective of the demonstrations at OC and HSR was to perform above tasks and to ascertain the extent of the advantages gained. The decision to pursue large-scale conversions will depend on the relative merits of each fuel, the energy picture, the availability and cost of conversion technologies, and the co-operation of transit authorities.

Propane and natural gas are sufficiently different fuels to warrant separate consideration. Propane is delivered and stored as a liquid at moderate pressures (less than 300 psi), its energy content is approximately 67% that of diesel fuel and it is heavier than air. Natural gas, on the other hand, is delivered as a low pressure gas; it is then compressed on-site and stored at 3000 psi on the vehicle. Its energy content at this pressure is approximately 20% of that of diesel fuel and has the safety advantage of being lighter than air. These characteristics suggest that propane on the whole, is a more readily exploitable fuel. However, natural gas seems to have a long-term advantage with respect to supply, price stability and cost. The propane and natural gas demonstrations were both conceived as two-phase programs. In the

first phase, a single bus would be converted and subjected to a GO/NO-GO test with well-defined fuel consumption and performance criteria and to a short-term service run. Upon successful completion of this phase, a fleet of buses would be converted and put through a minimum of one year in-service evaluation.

Both demonstrations are curently in their second phases. In the following two sections of this paper, the OC and HSR experiences will be presented separately. In parallel to these demonstrations, MTC commissioned the Ontario Research Foundation (ORF) to perform an engine test evaluation of the propane and natural gas engines along with their diesel counterparts. The results obtained to date in this work are summarized to provide an indication of the potential of current engines and fuels used in these demonstrations.

OC TRANSPO DEMONSTRATION

STATUS

The OC Transpo demonstration was initiated during 1983 with some assurance that the propane conversion technology, including heavy-duty propane engines, was available. The North American engine suppliers, unfortunately, declined to supply such engines, and, therefore, a European propane engine, the IVECO (Fiat) 8220.72 LPG, was selected for the project. This engine is based on a four-stroke, 9.6 L, in-line six-cylinder diesel block. Its conversion to a spark-ignition propane mode was accomplished by Dereco, a Swiss subsidiary of IVECO. The engineering of this engine into 1979 GM "New Look" buses to replace two-stroke Detroit Diesel 6V71 engines and to mate with Allison V730 transmissions was accomplished at OC with the assistance of Dereco and Hovey and Associates.

The on-board propane storage system was custom built for this program. It consists of four manifolded conventional tanks forming an 800 L preassembled unit. It includes a mechanical float and a "spitter" valve to prevent filling beyond the 80% capacity, as required by safety regulations. This arrangement provides the buses with a minimum of 700 km range on propane.

A propane refuelling station was built at the St. Laurent garage by Superior Propane. The station allows refuelling of a bus within four minutes and includes a "dead-man's handle" and quick-release fuel hose couplings to provide for safety of operation.

At this stage, no modifications have been done to the bus depot. All buses are stored outdoors except during maintenance.

INITIAL OPERATING EXPERIENCE

The GO/NO-GO tests, including fuel consumption and performance measurements, were carried out during 1984. Fuel consumption of the propane bus and a diesel control bus were measured over a representative bus driving cycle on a test track at the Lete military base in Ottawa. The performance of the two buses were compared by measuring acceleration times. The results of these tests, as summarized in Table 1, were highly favourable for the propane bus. Thus, the project steering committee decided to proceed to the second phase of the project.

Since then, the OC Transpo propane bus fleet was gradually built to a strength of 10 buses by early 1986. Over the remaining one-year period of the demonstration, this 10 bus fleet will be kept in service to provide adequate operating experience.

In the first two years of the program, a number of technical difficulties have plagued progress. These more serious difficulties included premature engine, alternator and governor failures. The engine failures were traced back to engine operating conditions, especially high induction air temperature during summer, which resulted in severe engine knock. This problem was solved by the simultaneous application of a number of remedies:

- insulation of the inlet and exhaust manifolds,
- provision of additional ventilation for the engine compartment,
- retarding ignition timing and leaning air-fuel mixture.

The premature failure of the oil-cooled alternators was mainly due to improper sizing of the flow restrictor in the inlet oil line. The governor failures resulting in engine overreving were traced to excessive wear in a dry bushing. A further cause for engine overreving was the incorrect spring loading of the throttle which caused it to fail in the "open" mode. These and a number of smaller difficulties were addressed and solved by OC with assistance from suppliers and MTC staff.

From May to September 1986, the bus fleet has been operating free of any major reliability problems. According to OC Transpo staff, propane bus availability is now approximately 80%, which is deemed to be acceptable for a demonstration fleet. Fuel consumption, although not firmly established, is around 90 L/100 km. At the current (September 1986) propane price of 18¢/L, this translates into a fuel cost of 16.2¢/km. This figure compares favourably with the diesel fuel cost of 22.7¢/km, which is based on a 53.7 L/100 km diesel fuel economy and 42.3¢/L diesel fuel price. The 6.5¢/km fuel cost advantage translates into a $3750/bus/year saving for a typical transit bus with a 55 000 km/year service. Although the capital and labour costs of the bus conversion were

substantial, the price of mass-produced propane buses should not be significantly higher than those of comparable diesel buses.

The remaining hurdles to the adoption of propane as a bus fuel are:

- Difficulty of indoor bus storage: Outdoor storage does not seem to be acceptable under Canadian climatic conditions.
- Lack of reliable North American propane engine packages.

HSR NATURAL GAS BUS DEMONSTRATION

STATUS

The HSR natural gas bus demonstration was initiated in 1985 primarily for environmental reasons, i.e., the need to find economically viable alternatives to the diesel with lower pollution and noise levels. The timing of the program was especially opportune since Hamilton has decided to replace its aging Wentworth Street facility with a new garage which can be constructed to be compatible with an alternative fuel.

The conversion of the six-bus demonstration fleet is being carried out with 1977 "New Look" GM buses in which two-stroke diesels are replaced by four-stroke spark-ignition natural gas engines. These are very similar to the propane engines used by OC. The major difference between the natural gas and propane IVECO 8220 is the compression ratio. The selection of the 12:1 ratio for the natural gas engine was a conservative one and resulted from our experience at OC. Sufficient on-board fuel storage is accomplished by the use of seven 110 L fibre-wound aluminum cylinders. These 33 cm outside diameter and 183 cm long cylinders are mounted under the bus and manifolded by stainless steel tubing. The use of steel cylinders is not recommended due to weight considerations. Crash test results with the aluminum cylinders indicate that they have a very wide margin of safety.

A natural gas refuelling station was constructed at the Wentworth St. garage under the direction of Union Gas. The station employs a 149 kW (200 hp), 340 m^3/h 200 cfm compressor and is capable of refuelling all six buses within four hours to the maximum 20.7 MPa (3000 psi) tank capacity. During the demonstration period, the buses will be stored outdoors, except during maintenance. However, indoor storage is permissible with the installation of fire safety-related equipment, especially natural gas detectors and alarm systems. The cost of provision for such measures in the new garage does not seem to be prohibitive.

INITIAL OPERATING EXPERIENCE

The first natural gas bus became available during the fall of 1985 at which time it was put through a series of GO/NO-GO tests. In these tests, the fuel consumption, range and performance of the bus were assessed over a simulated test track circuit and an urban/suburban cycle in Hamilton. The circuit ran from the Wentworth St. garage to the Mountain garage over the "Mountain route." The complete test cycle included four runs over this circuit, which amount to 130 km of driving.

The GO/NO-GO tests were conducted with three buses loaded to 2200 kg:

- the CNG bus
- the standard two-cycle diesel equipped bus
- the four-cycle diesel equipped bus

The main test results, summarized in Table 2, indicate that:

- the CNG bus is reasonably fuel efficient -- it consumed only 10% more energy than the diesel baseline;
- it can negotiate the 7% grade with 73 passengers on board at the same speed or better than the diesel bus; and
- it has an estimated range of 375 km.

These results met and exceeded the acceptance criteria set by the project steering committee and thus allowed the initiation of the second phase of the project.

The fuel-economy data obtained over the limited GO/NO-GO test can be used to estimate the fuel-cost advantage of the CNG bus. The present price of natural gas and diesel fuel to HSR are 28.7¢/kg and 52.4¢/kg (43¢/L), respectively. At these prices, the fuelling costs are 12.1¢/km and 22.7¢/km for the CNG and diesel buses, respectively. At these rates, the annual fuel cost-saving of a CNG bus on a 55 000 km service would be $5824. However, significant capital and operating expenses have to be incurred to reap this benefit. A better estimate of these expenses will be provided at the completion of the demonstration.

At present, HSR has one CNG bus in service while the remaining five buses are being converted. Due to experience gained at OC Transpo and immediate transfer of this information to HSR, fewer difficulties have been encountered in Hamilton. During the limited service life, bus drivers and garage personnel have expressed great satisfaction with the performance of the CNG bus. The superior driveability, noise and pollution (smell) characteristics of the bus are being greatly appreciated.

Bus operation presented only one major inconvenience -- cold-starting during winter. This difficulty could be alleviated by employing a positive pressure rather than the negative

pressure carburetion system originally used. A second inconvenience involves the limitation of minimum tank pressure to 10.3 MPa (1500 psi) rather than 20.7 MPa (3000 psi). This temporary precaution will be eliminated soon, when the safety burst discs of the storage cylinders are upgraded.

The six-bus CNG fleet is expected to go into full service by January 1987 and to remain in full service for at least one year. During this demonstration period, substantial operating and maintenance data will be collected with the buses and the fuelling station.

ENGINE TEST RESULTS

In parallel with these demonstrations, an engine test project was conducted at the Ontario Research Foundation (ORF) under contract to MTC and EMR. This project provided accurate comparative data on the performance, efficiency and exhaust emissions of the IVECO propane and natural gas engines relative to those of the two-stroke DDA and four-stroke IVECO diesel engines. Some of the specifications of these engines are provided in Tables 3 to 6.

The relative efficiency and exhaust emissions of the four engines were assessed by engine dynamometer simulation of the Advanced Design Bus (ADB) test cycle, which is a composite driving cycle representing bus service in central business districts, on arterial roads and in commuter runs. Each of these three modes are represented by specific cycle components described in Figures 1 to 3. A combination of these three-cycle components along with "idle" periods make up the total ADB cycle.

Simulation of the ADB cycle necessitates knowledge of the engine torque and speed requirements of the bus on the driving cycle. This data was obtained from the GM bus division, and it was used for the computer control of the engine and the dynamometer during the cycle simulation at ORF. Although with an eddy current dynamometer it is virtually impossible to follow the cycle precisely, total work delivered by each engine over the test cycle did not vary by more than 4 to 5% from the average value. In addition, repetitive testing over the cycle with the same engine resulted in less than 2% variation in total work. Thus, results presented below qualify as the basis for an accurate comparison.

Before measuring fuel consumption and exhaust emission levels over the ADB cycle, the torque characteristics of each engine were determined by measuring maximum torque over the engine speed range of 1000 to 2100 rpm. The results of this work as presented in Figure 4 indicate that within the normal operating range of a bus engine, i.e., 1500 to 2100 rpm, the four

engines are 5 to 15% apart in maximum torque. Among the four engines tested, the natural gas engine appears to have the best torque characteristics while the IVECO diesel the worst.

At the top speed of 2100 rpm, the three IVECO engines produce, as specified, approximately the same torque and power, i.e., 595 Nm and 131 kW (175 hp). The DDA 6V71 tested in this program produced, at 2100 rpm, a torque of 554 Nm and a power of 122 kW (163 hp). Thus, with respect to power, all three IVECO engines should be acceptable in most transit operations in Ontario.

Engine efficiency was determined by measuring fuel consumption and total mechanical work delivered over the ADB cycle. The efficiency over the cycle or, as is commonly referred, the cycle efficiency η is given by

$$\eta = \frac{\text{Mechanical Work Delivered} \times 100}{\text{Total Fuel Energy Consumed}} \quad (\%)$$

This measure of efficiency is particularly suitable when a variety of fuels and engines are used over a common cycle. The results of this analysis are presented in Figure 5, which indicates that the IVECO four-stroke diesel is 16.7% more efficient than the DDA two-stroke diesel engine. As expected, the four-stroke diesel is more efficient than the two-stroke one, since its operation is far better controlled by its valve train. The pleasant surprise is the high efficiency of the propane engine. It is seen to be 11.1% more efficient than the DDA diesel and only 4.8% less efficient than the IVECO diesel. Unfortunately, in its present state, the natural gas engine is not as efficient. However, optimal calibration of this engine, especially with respect to ignition timing and air/fuel mixture control, is expected to remedy this condition. This optimization, which the propane engine has partially experienced, will be carried out with the natural gas engine at ORF in the near future.

The emissions of particulates as well as gaseous pollutants including carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x) were measured over the ADB cycle. These measurements were done by sampling the exhaust gas over the entire test cycle and by subsequent chemical analysis of the sampled gas. The particulate emission results in Figure 6 clearly demonstrate the superiority of the gaseous fuels to the diesel. The very low levels of particulates, 0.015 to 0.028 g/hp·h, are expected to emanate largely from the engine lubricant rather than the gaseous fuels. These levels could be further improved by means of reducing lubricant consumption such as the use of valve sleeves.

The emission levels of CO and HC in the four engines are comparable. The natural gas engine appears to enjoy an advantage in CO emissions. Its HC emissions are higher; however, most of the HC is known to be unburnt methane which is relatively inert and benign.

The NO_x emissions of the propane and natural gas engines are, unfortunately, substantially higher than those of the diesel engines, as seen in Figure 9. Although this is an unfavourable result, it is not an unexpected one since none of the engines tested have any pollution control equipment. It is expected that application of one or more of the well-developed NO_x control strategies, such as lean combustion, exhaust gas recirculation and catalyst reduction, will ameliorate this condition. Work along these lines is being planned by the project team.

It should be noted that the emissions data presented in this paper cannot be directly compared against the emission standards in Table 7, which are based on the Environmental Protection Engine (EPA) cold-start transient test cycle rather than the ADB cycle. The emissions data presented here do, however, allow consistent comparisons of the four engines.

CONCLUSIONS

The OC Transpo and HSR propane and natural gas transit bus demonstrations are proceeding successfully. The feasibility of successful bus conversions and refuelling has been established. Initial engine and component reliability problems have been cured, and the acceptability of the buses with respect to fuel consumption, performance and range have been established. During the next one to two years, the two bus fleets will be carefully monitored to yield detailed operating data, primarily on reliability, maintenance, and energy consumption.

The initial driver and rider experiences with the propane and natural gas buses are favourable. Lower noise, vibration and odour levels as well as superior acceleration performance appear to be appreciated. However, outdoor parking and fuelling produce major inconveniences.

A comparative engine test program was conducted at ORF to support the demonstrations. The results of this program indicate that the gaseous fuel engines have excellent torque characteristics, very low particulate emissions and rather high efficiencies. However, in their present state, they emit more NO_x than the diesel engines. Further optimization and application of emission control measures are expected to maximize efficiency and to reduce NO_x emissions.

ACKNOWLEDGEMENTS

This paper has been made possible by the work of many, all of whose names cannot be listed here. I wish to specificlly thank the following: Bill Jenkins (OC), Roy Duncan (HSR), Reginald Webb (R.E. Webb Inc.), Wendell Goetz (ORF), Meinrad Signer (Dereco), Jeff Turner (MTC), and Dave Petherick (MTC).

TABLE 1/ OC Transpo Propane Bus Demonstration
Go / No-Go Test Results

	Diesel (DDA 6V71)	Propane
Fuel consumption (L/100 km)	53.65	91.4
Fuelling cost (¢/km)	22.7	16.2
Average speed in downtown route (km/h)	14.9	15.4
Average speed on suburban route (km/h)	34.0	34.8
Acceleration time, 0-60 km/h (s)	28	30
Acceleration time, 0-80 km/h (s)	77	87
Interior noise		less than diesel
Vibration		less than diesel
Particulate emissions		not detectable

TABLE 2/ Natural Gas Bus Demonstration
Go / No-Go Test Results

	Diesel (DDA 6V71)	Natural gas
Fuel consumption (kg/100 km)	43.4	42.2
Fuelling cost (¢/km)	22.7	12.1
Average speed (km/h)	35.2	36.6
Estimated range (km)		375
Acceleration performance		superior to diesel
Noise		less than diesel
Vibration		less than diesel
Particulate emissions		not detectable

TABLE 3/ Engine Specifications, DDA 6V71 NA

Engine configuration	V6. two-stroke
Firing order	1-6-3-5-2-4
Displacement	6.99 L
Bore	108 mm
Stroke	127 mm
Compression ratio	17:1
Fuel system	Unit injectors
Size	C 55
Rated power	128 kW at 2100 rpm
Torque	675 Nm at 1000 rpm
Induction system	Scavenging blower

TABLE 4/ Engine Specifications
IVECO 8220 Diesel NA

Engine configuration	Inline 6, four-stroke
Firing order	1-4-2-6-3-5
Displacement	9.57 L
Bore	125 mm
Stroke	130mm
Compression ratio	17:1
Fuel system	BOSCH hydraulic injectors
Governor	RQV variable speed
Rated power	147.4 kW at 2600 rpm
Rated torque	592 Nm at 1400 rpm
Induction system	Naturally aspirated

TABLE 5/ Engine Specifications
IVECO 8220.72 LPG (Propane)

Engine configuration	In-line 6, four-stroke
Firing order	1-4-2-6-3-5
Displacement	9.57 L
Bore	125 mm
Stroke	130 mm
Compression ratio	10.9:1
Fuel system	LPG - IMPCO CAG 425-20-6 carburetor V2-19 - IMPCO model E EOS-20 (o)
Governor	Holly vacuum
Rated power	126 kW at 2100 rpm
Rated torque	678 Nm at 1000 rpm
Induction system	Naturally aspirated

TABLE 6/ Engine Specifications
IVECO 8220 CNG (Natural Gas)

Engine configuration	Inline 6, four-stroke
Firing order	1-4-2-6-3-5
Displacement	9.57 L
Bore	125 mm
Stroke	130 mm
Compression ratio	12.0:1
Fuel system	NG - IMPCO CAG 425-20-6 carburetor V2-10 - IMPCO model E EOS-20 (o)
Governor	Holly vacuum
Rated power	126 kW at 2100 rpm
Rated torque	678 Nm at 1000 rpm
Induction	Naturally aspirated

TABLE 7/ Heavy-Duty Diesel Emission Standards

	Canada	US
	1988 g/hp-h	1991 g/hp-h
HC	1.5	1.3
CO	15.5	15.5
NO_x	6.0	5.0
Particulates	0.6	.10

Figure 1/ Advanced Design Bus Cycle -- Arterial Phase

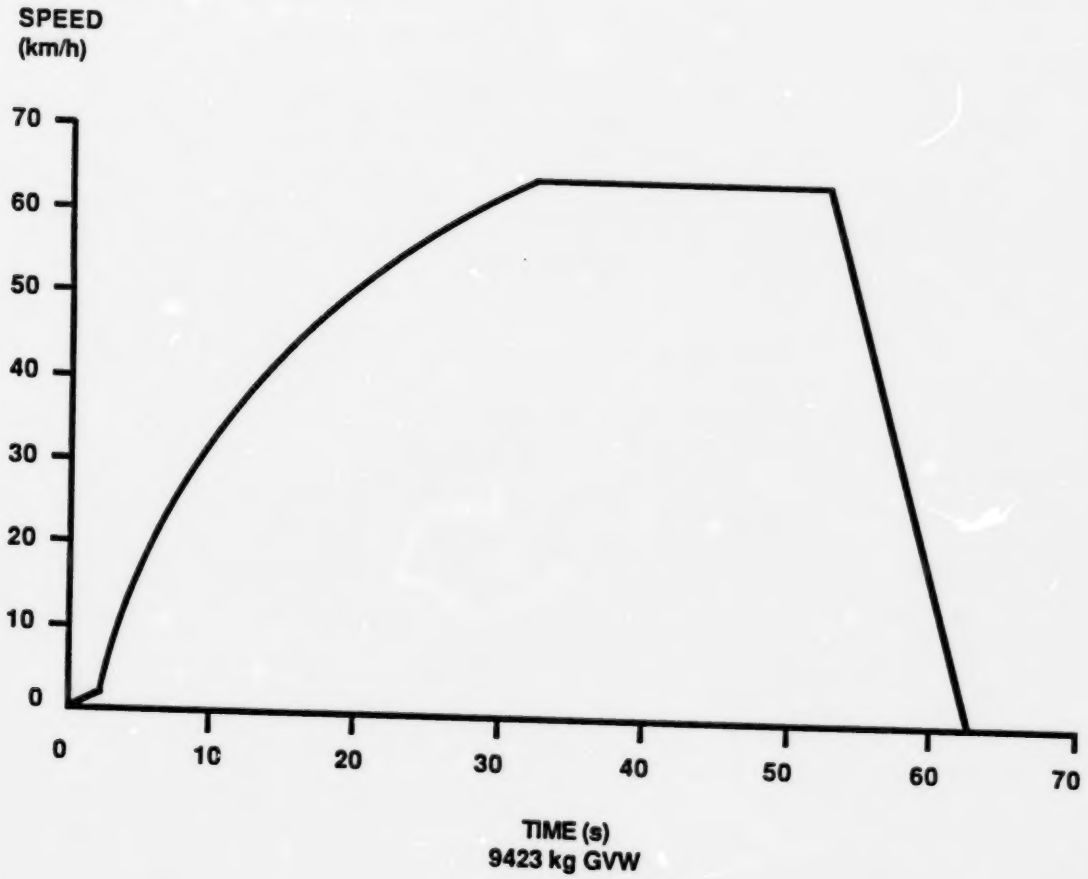

Figure 2/ Advanced Design Bus Cycle -- Central Business District Phase

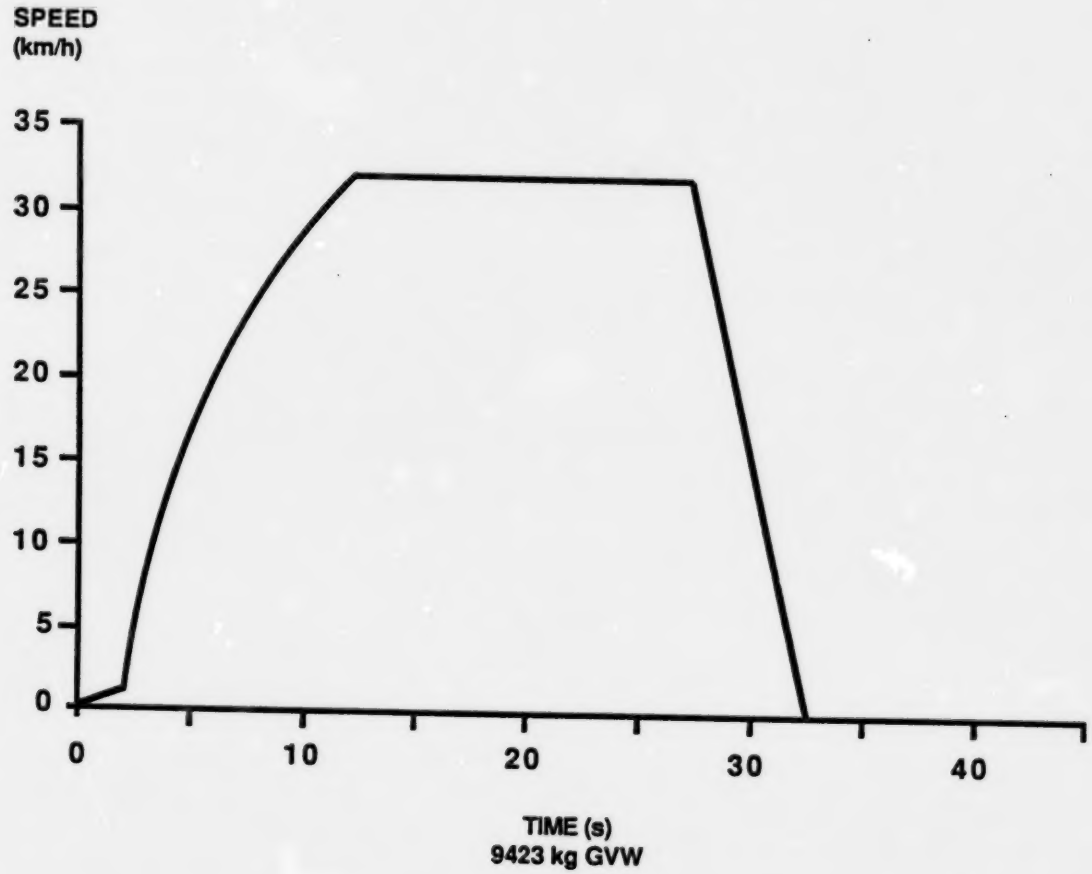

Figure 3/ Advanced Design Bus Cycle -- Commuter Phase

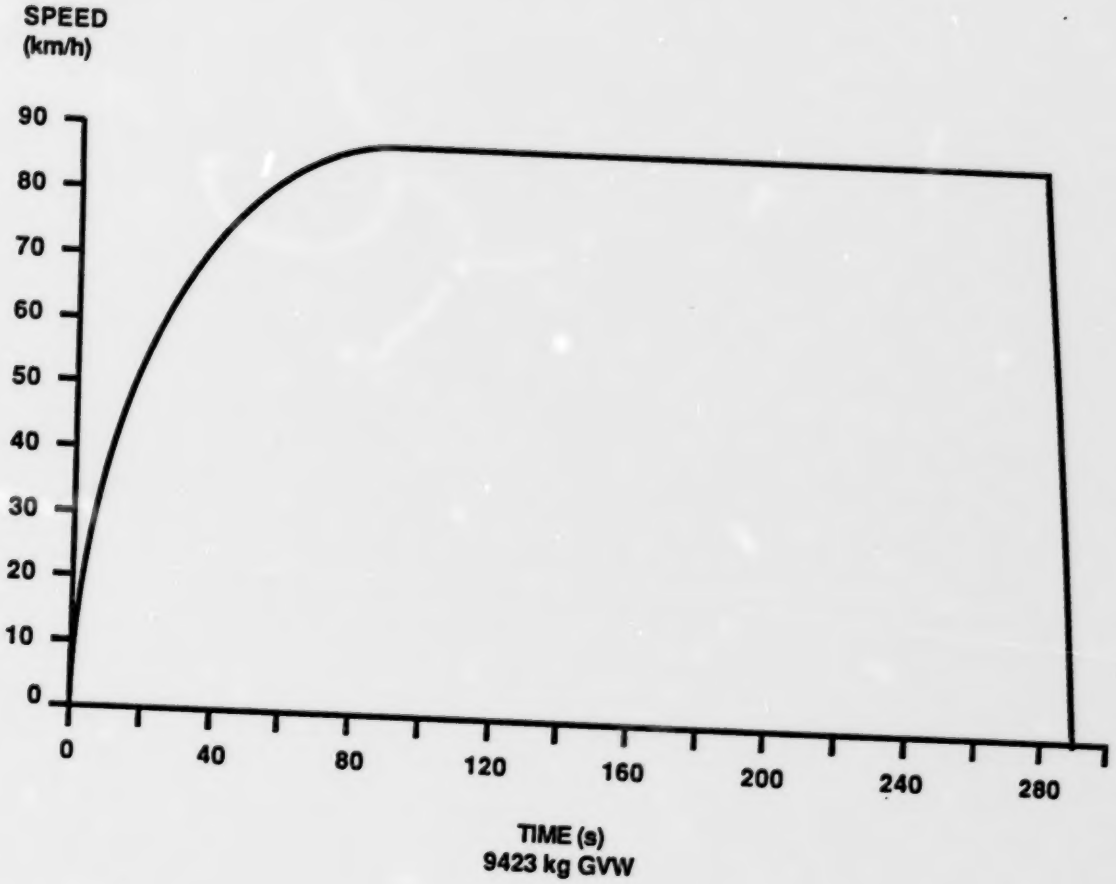

Figure 4/ Comparison of Maximum Torque Curves of Four Bus Engines

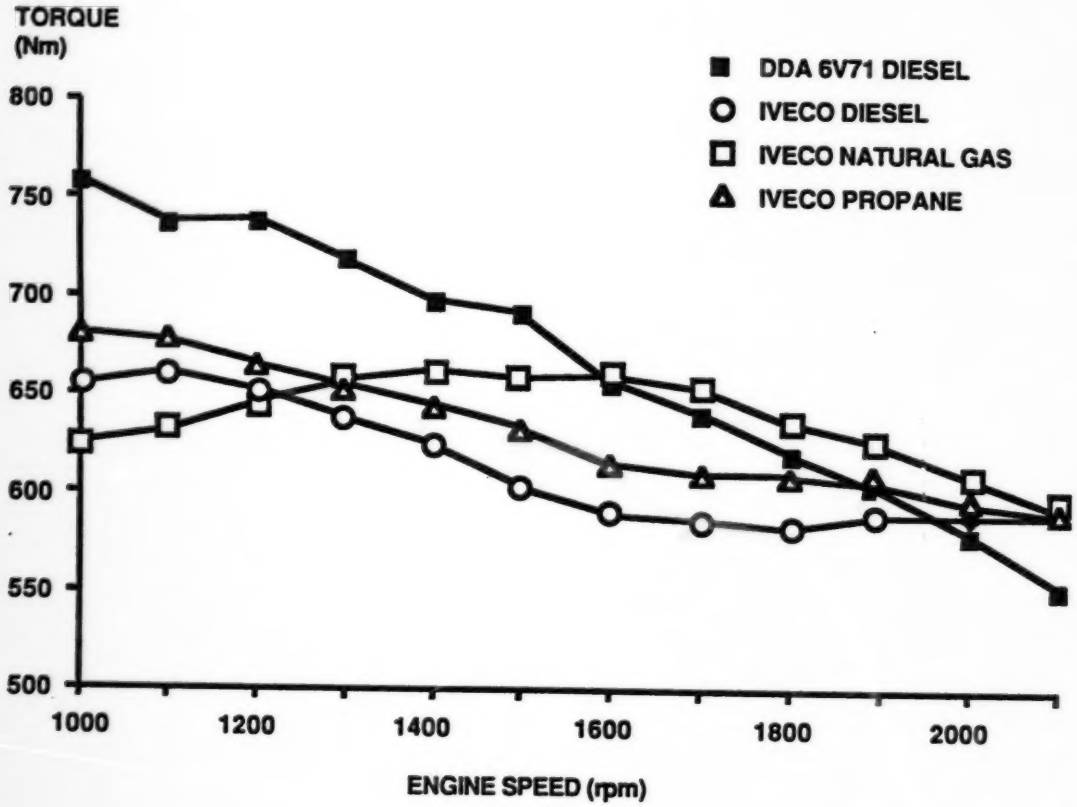

Figure 5/ Bus Engine Efficiency

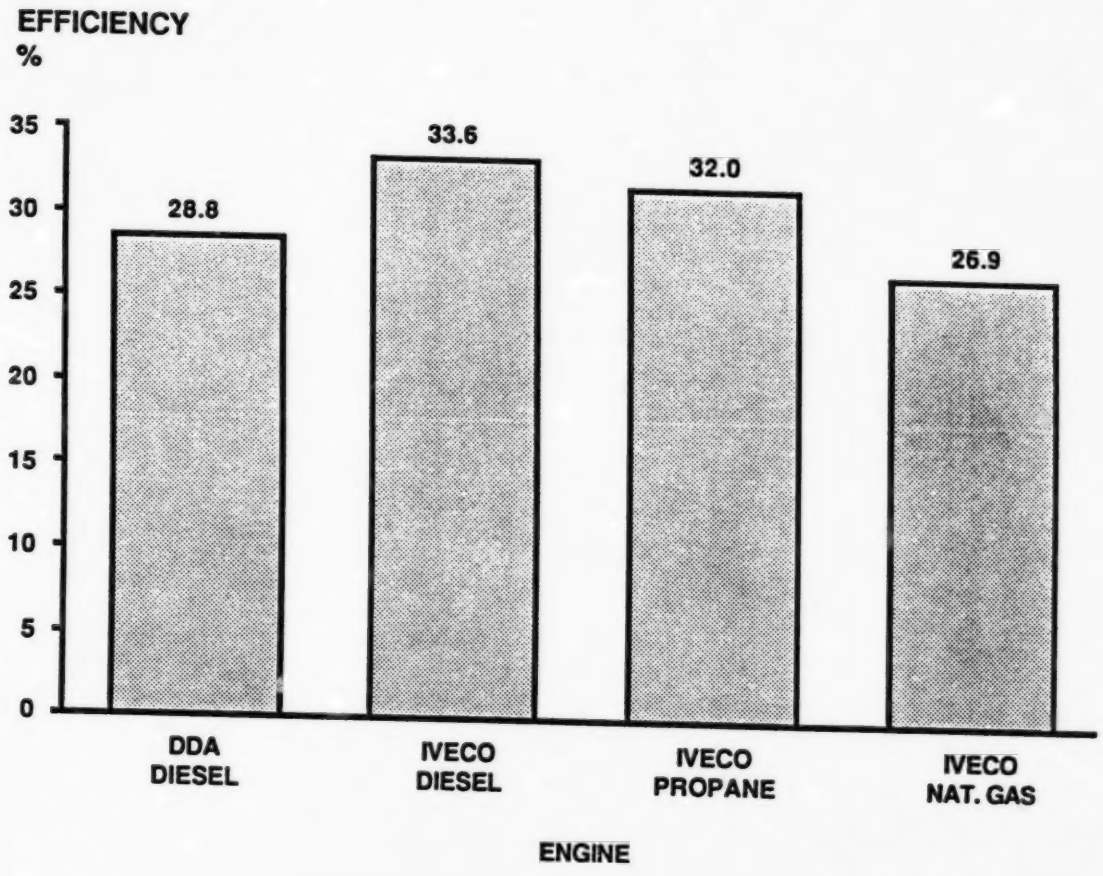

Figure 6/ Bus Engine Particulate Emissions Over the ADB Cycle

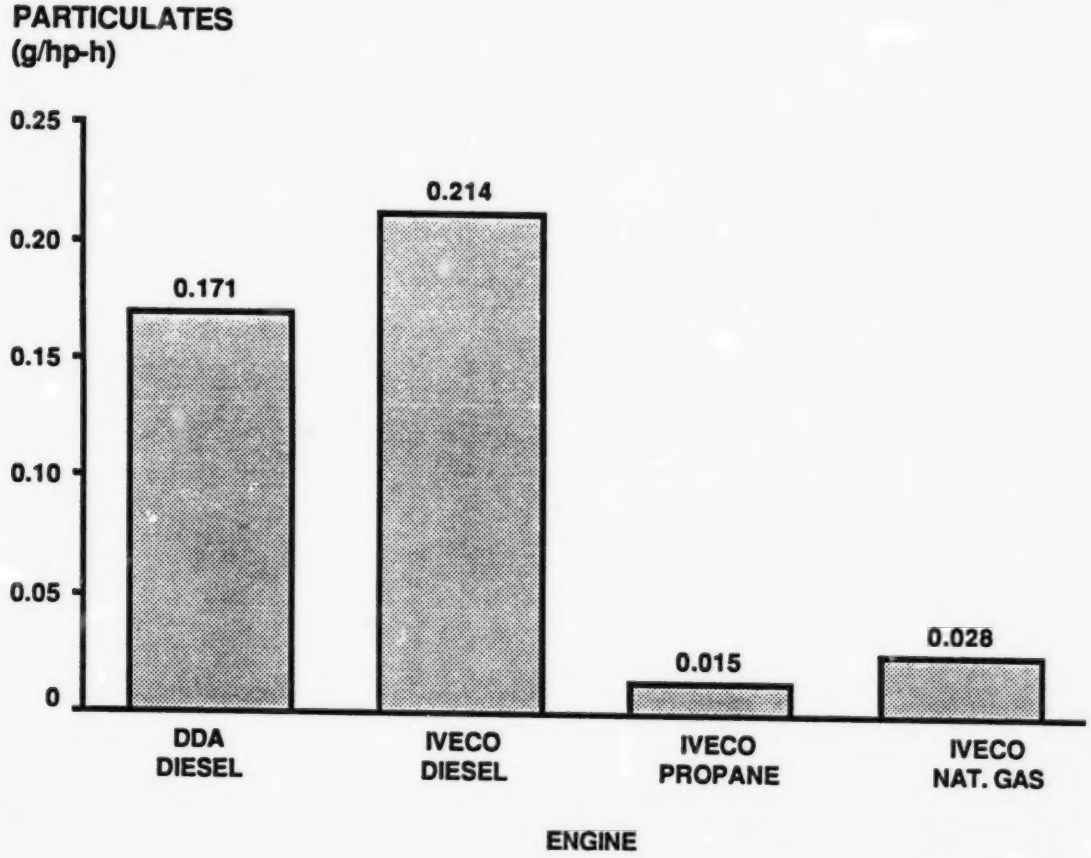

Figure 7/ Bus Engine CO Emissions Over the ADB Cycle

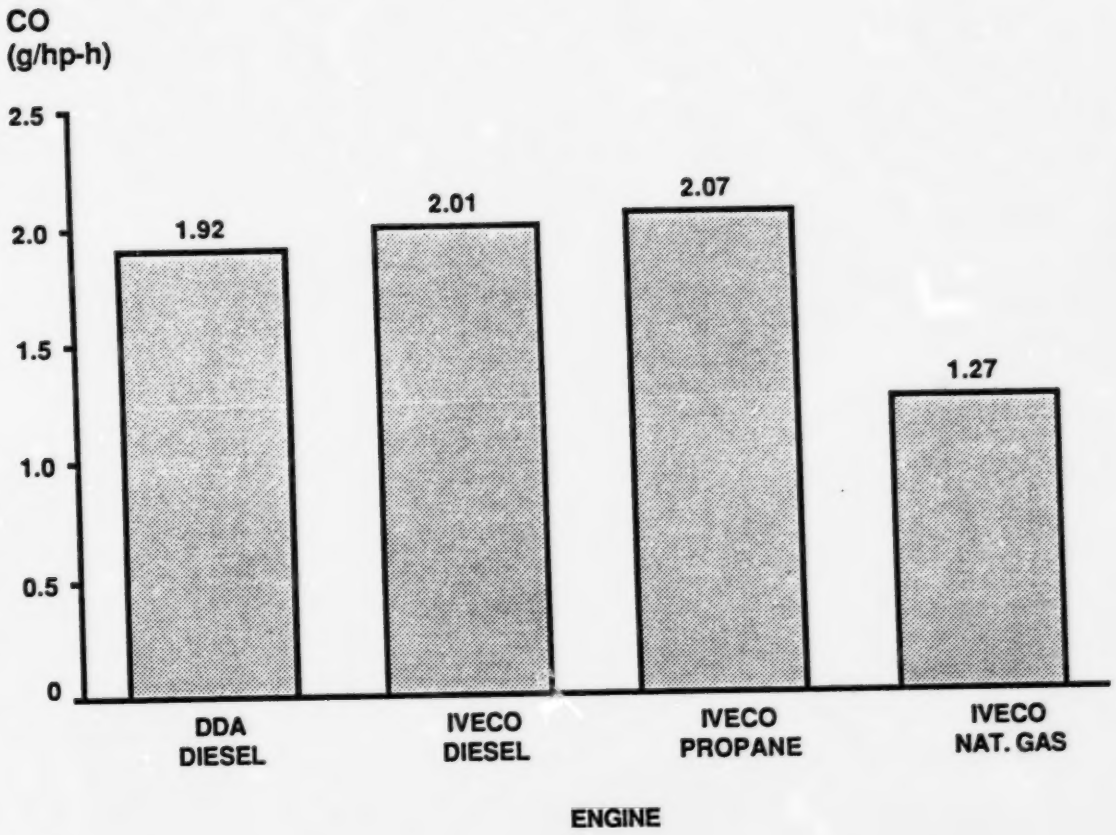

Figure 8/ Bus Engine HC Emissions Over the ADB Cycle

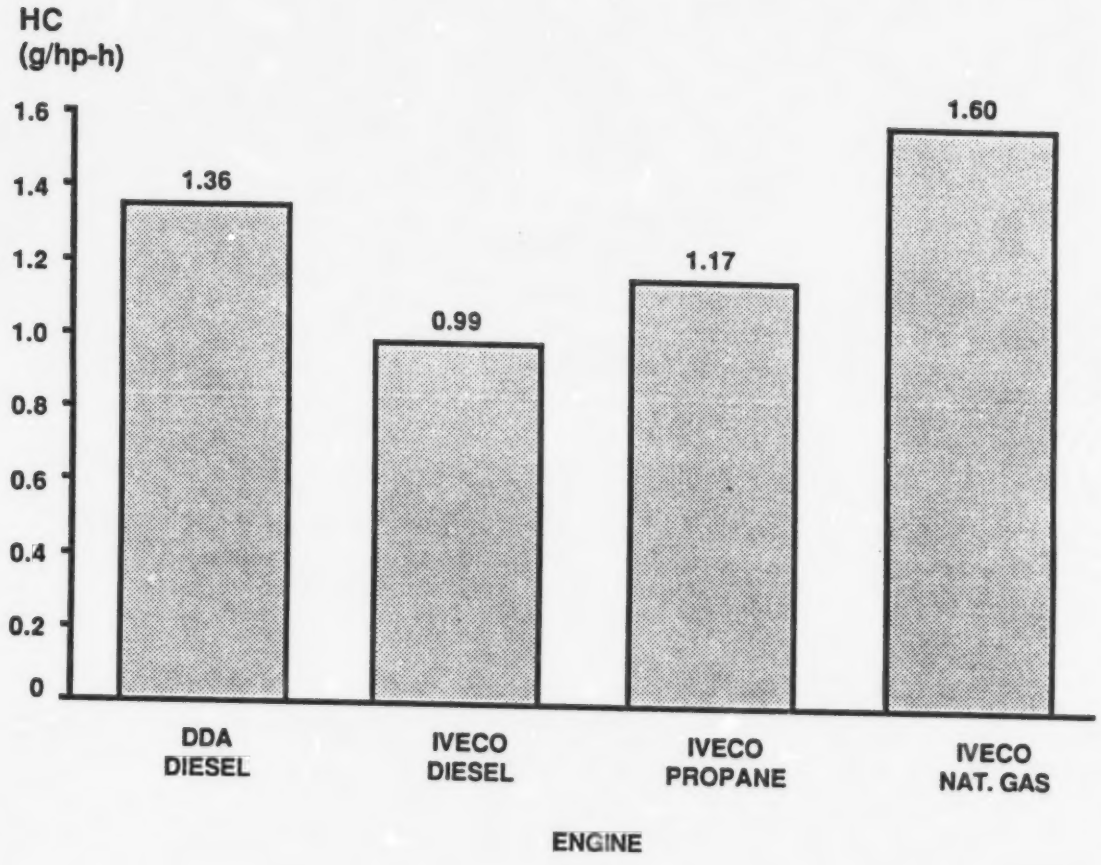

Figure 9/ Bus Engine NO_x Emissions Over the ADB Cycle